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*Waste Manag Res* published online 17 May 2012

DOI: 10.1177/0734242X12443584

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Waste Management & Research  
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## Abstract

This work analyses how selective collection evolved over the period 1998–2007 in Spanish towns and cities with more than 50 000 inhabitants. To do so, both the legislation in force during the years included in the study and logistic factors, such as the radius of action of the pick-up points, were taken into account. Information about the towns and cities was obtained from a survey sent out in 1998 and 2007 to the councils of the municipalities included in the study. The results obtained in the two years show that the most widely implemented separate collection system in 1998 no longer existed in 2007 but, in order to comply with the law, had been transformed by adding new fractions, above all that of lightweight packaging. To determine whether the targets set by law as regards recovery and recycling were met in the two years, an efficiency indicator was used to evaluate the effectiveness of the collection systems. Results show how separation increased in the paper/board and glass fractions.

## Keywords

Municipal solid waste, separate collection, collection system, legislation, efficiency

## Introduction

Due to the large number of factors that must be taken into account when establishing a separate collection system (which may be economic, social, environmental or legal, among others), there is no single solution or alternative when it comes to designing them. For this reason, many authors have focused their research on how waste collection is influenced by design or logistic factors, such as collection staff, collection frequency, number of collection vehicles, distances to be walked by citizens, etc. (Bach et al., 2004; García-Sánchez, 2008; González-Torre and Adenso-Díaz, 2005; Jenkins et al., 2003; Wilson and Williams, 2007).

In order to meet the targets specified by the legislation, a large range of collection systems can be found throughout Spain and abroad. This fact has led researchers to compare different collection systems in an attempt to determine which type of system works best (Ayerbe and Pérez, 2000; Dahlén et al., 2007; Mattson et al., 2003; Woodard et al., 2007).

The present study analyses how the efficiency of different separate collection systems in Spanish municipalities have evolved in order to meet the targets specified by the legislation. The study analyses the separation rate indicator and how it is influenced by the logistic variable *Radius* using linear regression. The study was carried out by means of a single survey that was sent out in 1999 and 2008 to the city councils of municipalities with more than 50 000 inhabitants, which together account for over 50% of the Spanish population. The data obtained from the answers and the legislation in force in each year were then used

to determine which systems had been most successfully adapted to comply with the regulations. The findings of the study are also intended to be useful for the development of future collection systems.

## Evolution of the legislation

With regard to the evolution of the legislation on packaging and packaging waste, the recovery targets in the first Directive on this subject (Directive 94/62/EC) were:

- ‘no later than five years from the date by which this Directive must be implemented in national law, between 50% as a minimum and 65% as a maximum by weight of the packaging waste will be recovered’;
- ‘within this general target, and with the same time limit, between 25% as a minimum and 45% as a maximum by weight of the totality of packaging materials contained in packaging waste will be recycled with a minimum of 15% by weight for each packaging material’.

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In Spain, it was not until the passing of Directive 94/62/EC into the Spanish Law on Packaging and Packaging Waste, Law 11/1997, that separate collection began on a widespread scale throughout the country.

The new Directive (Council Directive 2004/12/EC) is far stricter and raised the recovery targets to be achieved in 2008, which now stand at:

- 'no later than 31 December 2008 60% as a minimum by weight of packaging waste will be recovered or incinerated at waste incineration plants with energy recovery';
- 'no later than 31 December 2008 between 55% as a minimum and 80% as a maximum by weight of packaging waste will be recycled';
- 'no later than 31 December 2008 the following minimum recycling targets for materials contained in packaging waste will be attained:
  1. 60% by weight for glass;
  2. 60% by weight for paper and board;
  3. 50% by weight for metals;
  4. 22.5% by weight for plastics, counting exclusively material that is recycled back into plastics;
  5. 15% by weight for wood'.

The targets established in the 11/1997 law on Packaging and Packaging Waste were modified by means of Royal Decree 252/2006 in order to adapt them to the new European regulations. The progressive changes introduced into the legislation have meant that town councils have also had to evolve the methods and programmes of separate collection they use in order to adapt to the new limits established by the legislation.

## Materials and methods

### *The separate collection system*

Directive 2008/98/EC defines 'separate collection' as the collection in which a waste stream is kept separate by type and nature so as to facilitate a specific treatment. Depending on the distance that citizens must travel to the waste drop-off point, several levels of storage can be distinguished.

- *Door to door*. Wheelie bins are located at each door or some other point that is easily accessible from the household or building. The distance to be covered in order to deposit the waste is kept to a minimum.
- *Kerbside collection*. Drop-off points are located along pavements every 50–60 m. Citizens do not have to travel very far and the system is well accepted. This is applied in cities with a high population density.
- *Drop-off points (DP)*. The drop-off points are located at greater distances, usually between 100 and 200 m. The sys-

tem relies on the citizens' willingness to travel greater distances on foot.

By combining the different types of sorting at source with the different levels of drop-off, a wide range of collection models can be obtained (Gallardo et al., 1999).

### *Survey*

A survey based on methods of Miquel et al. (1997) was designed by the authors specifically to gather information about the collection systems implemented in the towns and cities, the composition of the waste, the gross amounts of each fraction collected separately, the number of pick-up points and the city surface.

The same survey was sent out to all City Councils (Environmental Department) from cities with populations of over 50 000 inhabitants in the two years, since the sum of these municipalities accounted for 50.95% and 52.54% of the total population in 1998 and 2007, respectively (INE, 1998, 2007).

The survey was sent out to City Councils by post, as the numbers included in the study were not very high: 116 in 1998 and 137 in 2007. A month later the Councils that had not answered the survey were phoned as a reminder. Most of them asked us to send them the survey by email. Six months after sending the surveys out, researchers gathered the information for analysis.

### *Definition of the efficiency indicator*

In order to determine the degree of efficiency of the collection process, first a set of indicators needs to be defined (Gallardo et al., 2010). In this study only the separation rate ( $SR_i$ ) was used as an indicator of the efficiency of the system. The  $SR_i$  is defined as:

$$SR_i = \frac{\text{Gross amount of waste collected in container for } i}{\text{Total amount of } i \text{ waste generated}} \times 100(\%),$$

where  $i = p, g, lp$ , for paper/cardboard, glass and lightweight packaging, respectively. Lightweight packaging includes plastic, metal and liquid packaging board. This index is used to determine what percentage of recyclable material has been collected correctly.

### *Definition of the logistic variable*

In this section, the logistic variable  $Radius_i$  is defined. This is one of the variables that can have an influence on the  $SR_i$ . Another logistic variable that can influence collection efficiency is its frequency (González-Torre and Adenso-Díaz, 2005) but in a previous study by Gallardo (2000), which corresponds to the analysis of cities in 1998, it was found that the only variable that influences the  $SR_i$  was  $Radius_i$ . For this reason, in order to compare the years 1998 and 2007, only this variable is considered. The variable  $Radius_i$  represents the radius of the area covered by each

DP and is calculated through surface data (in m<sup>2</sup>) and number of pick-up points. It is defined as the maximum distance a citizen must travel, in a straight line, to deposit his or her waste. It is a logistic or design variable that depends on the number of DP and can be modified by the technicians responsible for waste management. An equivalent variable, 'collection sites per km<sup>2</sup>', was used by Bach et al. (2004) to model the amount of paper that was collected.

Composition and collection data were used to calculate the different  $SR_i$ , while the variable  $Radius_i$  was calculated from the number of pick-up points and the surface area of the towns and cities.

Data about the collection of glass, paper/cardboard and packaging were analysed with the aim of establishing regression models that make it possible to obtain the  $SR_i$  of a material depending on the variable  $Radius_i$ .

Regarding to the kerbside collection, only two cases of lightweight packaging (system 2) are available, which therefore makes it impossible to perform a statistical analysis as in the case of DP.

## Results and discussion

### Participation

Results as regards participation were positive in both campaigns, and in addition to the surveys that were received, information was also obtained from other sources such as official websites or papers in national journals.

The participation results were 46% (53 out of 116) in 1998 and 33% (45 out of 137) in 2007. In both cases the sample was representative, since on applying the equations of Bartlett et al. (2001) for continuous data with  $t = 1.96$ ,  $e = 0.05$ ,  $S^2 = 0.04$  for 1998 and  $S^2 = 0.09$  for 2007 and a mean of 1.53 kilograms of urban waste per inhabitant for 1998 and 1.69 for 2007, it was found that the sample should contain 20 and 36 towns and cities in 1998 and 2007, respectively.

### Collection systems

As mentioned earlier, this work analyses how collection systems evolved between 1998 and 2007 in order to adapt to the

regulations that existed in the two years. After processing the data from both surveys, it was found that in total five collection models existed in both years, the characteristics of which are shown in Table 1. Cases in which it was not possible to extract complete information from the survey were not taken into account in the analysis.

It can be seen how the most widely used system in 1998 was System 5. The other systems (Systems 1 and 3) that were implemented were far less common and in most cases were pilot systems. By the year 2007 System 5 had disappeared (Table 1) because recovery of metal and plastic packaging had become compulsory. The same system evolved further still with the addition of the collection of lightweight packaging (System 1) and today it is the most widely implemented system in Spain. Another transformation of System 5 is System 4, in which the collection of the packaging and organic material fractions has been added. The system is the second system in terms of degree of implementation and is the one in which waste is sorted into the greatest number of fractions.

### Regression models

As can be seen in Table 1, all the systems include collection of paper/cardboard and glass at DP and only two have collection of lightweight packaging. In order to analyse these collections, linear regression models were established for the  $SR_i$  depending on the  $Radius_i$  in each of the years that were studied. With these models the aim is to determine how the distance to the wheelie bins affects the amounts that are collected. The equations for each of the models are shown in Equations (1) to (5), where it can be seen that in all the cases the level of significance ( $p$ -value) is below 0.05.

$$(1998) SR_p = -0.02Radius_p + 11.761; R^2 = 0.512, \\ p\text{-value} = 0.004 (1)$$

$$(2007) SR_p = -0.163Radius_p + 48.900; R^2 = 0.636, \\ p\text{-value} = 0.000 (2)$$

$$(1998) SR_g = -0.297Radius_g + 67.117; R^2 = 0.798, \\ p\text{-value} = 0.000 (3)$$

$$(2007) SR_g = -0.263Radius_g + 80.962; R^2 = 0.513, \\ p\text{-value} = 0.003 (4)$$

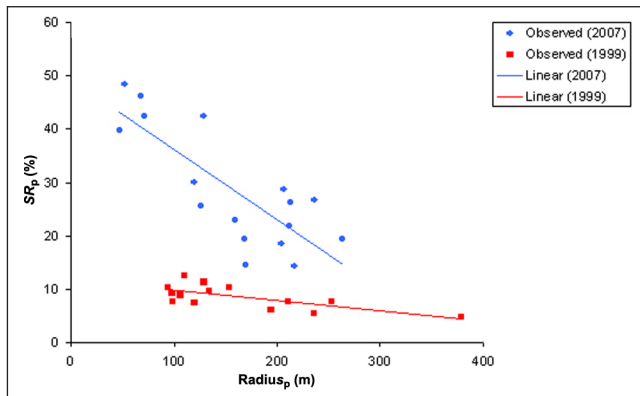
**Table 1.** Characteristics of collection systems

	Kerbside Kerbside			Drop-off points Drop-off points			No. cities No. of towns	
	Mixed waste	Organic waste	Lightweight packaging	Paper and cardboard	Glass	Lightweight packaging <sup>1</sup>	1998	2007
System 1	x			x	x	x	4	24
System 2	x		x	x	x		0	4
System 3	x	x		x	x		1	2
System 4	x	x		x	x	x	0	15
System 5	x			x	x		30	0

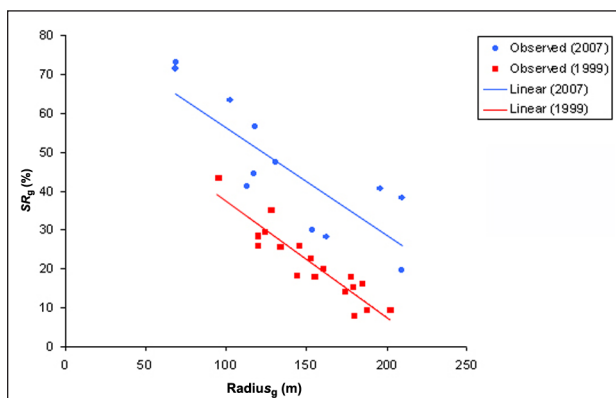
<sup>1</sup>Lightweight packaging includes plastic, metal and liquid packaging board.

$$(2007) SR_{ip} = -0.045 Radius_{ip} + 18.653; R^2 = 0.642, \\ p\text{-value} = 0.000 (5)$$

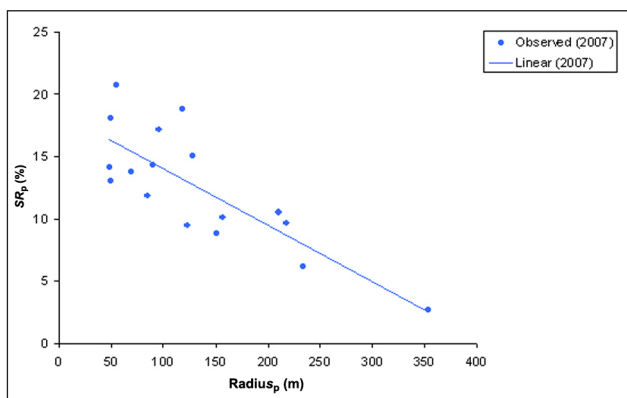
As can be seen in Figures 1, 2 and 3, in all cases the slope is negative; in other words: the higher the  $Radius_i$  is, the lower the  $SR_i$  will be. This is because the closer the bins are to citizens, the more willing they are to take part in separate collection. In contrast, in a study conducted in Sweden about the plastic packaging waste, Hage and Söderholm (2008) demonstrated that there were no differences between sparsely populated areas where people



**Figure 1.** Regression models for the separation rate of paper/cardboard.



**Figure 2.** Regression models for the separation rate of glass.



**Figure 3.** Regression model for the separation rate of lightweight packaging.

have longer distances to collection sites, and big cities where property-close collection is much more prevalent. That is to say, the plastic packaging waste rates were similar.

Considering the evolution over the two years of the study, in the case of paper/cardboard and glass it can be seen how, in the year 2007, the value of  $SR_i$  was always much higher for the same the value of  $Radius_i$ . For example, for a  $Radius_p = Radius_g = 100$ ,  $SR_p$  rises from 10 to 36% and  $SR_g$  increases from 37 to 55%. This means that over the 9 years examined in the study, citizens sort their waste more as a result of the numerous awareness-raising campaigns carried out by the public authorities with the aim of reaching the limits stipulated by the law. This comparison cannot be made in the case of lightweight packaging because in 1998 there were not enough data to be able to carry out a regression and see how it evolved.

As can be seen in Figure 1, the slopes of the two lines are different. The slope for 1998 is much less than that for 2007, which may be due to the different amount of information available to citizens. Separate collection of paper and cardboard began around 1998 and information was poor. At that moment, a good separation rate did not depend on the closeness between points and citizens. In contrast, in 2007 this type of collection had 10 years' experience behind it, so citizens were more aware (due to information campaigns) of the variable  $Radius_i$ . This does not happen in Figure 2, where the slopes are quite similar. This may be because in the 1960s and 1970s, Spain had a strong tradition of reusing glass and people were generally aware of this kind of collection. For this reason awareness has not changed in the last 10 years.

In Figure 1 it can be seen that the  $Radius_p$  have become smaller due to the increase in the number of pick-up points, the value being below 280 m in 2007 in all the municipalities. In the case of glass, in 1998 the number of pick-up points per town was higher than the number of points for paper/cardboard, because in Spain this fraction had been implemented earlier and had already evolved to some extent (Gallardo, 2000).

On examining the graphs in Figures 1, 2 and 3, it can be observed that for a short  $Radius_i$  (80 m) the percentages of glass sorted at source were close to the limits established by law in both years (25–45% in 1998 and 60% in 2007). However, this does not occur in the case of paper/cardboard (25–45% in 1998 and 60% in 2007) and lightweight packaging (25–45% in 1998 and 50% for metals, 22.5% for plastics and 60% for LPB in 2007, where the last value is the paper/cardboard target because it is the main component of this material), but paper/cardboard results are better than those for lightweight packaging. From data provided through private communications with companies responsible for recycling paper it is known that the main components of paper/cardboard bins are magazines, newspapers and cardboard boxes, while the remaining paper/cardboard waste (small cardboard packages) is left in the mixed (or co-mingled) waste bin. In the case of lightweight packaging, the low  $SR_{lp}$  values are due to the fact that this fraction has only recently been added to the collection of municipal solid waste and the amount of information citizens have in this case is still not as high as that available for the collection of paper/cardboard and glass.



## Conclusions

This work analyses how selective collection evolved between the years 1998 and 2007 in Spanish towns and cities with more than 50 000 inhabitants by taking into account the legislation in force in the years included in the study and logistic factors, such as the radius of action.

The data thus obtained showed that the most widely extended system in 1998 (System 5) had disappeared by 2007. This system consisted in collecting mixed waste in kerbside bins and paper/cardboard and glass from drop-off points. In order to fulfil the targets established by law, System 5 has been turned into System 1 by adding the collection of lightweight packaging and into System 4 by adding the collection of lightweight packaging and organic waste. These are the two systems that are most widely used today.

An efficiency indicator, the separation rate ( $SR_i$ ), was also used to analyse whether the percentages required by law are actually being recovered or not. By calculating the  $SR_i$  it was concluded that the minimum values stipulated by law are only reached in the case of glass collection. In the case of the collection of paper/cardboard and lightweight packaging, towns and cities manage to meet the recycling targets by adding packaging from rest waste treatment facilities. In such facilities the packaging is sorted by hand and the waste that is recovered from them is of lower quality.

Linear regression models were established using the  $SR_i$  and with the radius of action of each of the collection fractions ( $Radius_i$ ) and it can be seen that the value of the indicator  $SR_i$  increases as  $Radius_i$  decreases. Another conclusion that can be drawn from the graphs obtained in the study is that over the nine-year period that was analysed, the sorting of paper/cardboard and glass waste has increased. This is due, on the one hand, to the fact that citizens are made aware of the environmental problems and of the importance of recycling; and on the other hand, to the increasingly strictness of the legislation.

These findings provide disposal operators from other countries with useful information about the collection systems and how efficient they are in towns and cities with over 50 000 inhabitants, and this case can be used to design new collection systems: combining a good container location with a proper collection frequency and information campaigns.

## Acknowledgements

The authors are grateful to the Spanish Ministry of the Environment for financial support and to the City Councils that took part in the study for providing data.

## Funding

This work was supported by the Spanish Ministry of the Environment [Expedient numbers 279/2006/2-2.1 and AA228/2007/1-02.1].

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